TELKOMNIKA, Vol.12, No.1, March 2014, pp. 53~62
ISSN: 1693-6930, accredited A by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v12i1.1966

Line Differential Protection Modeling with Composite Current and Voltage Signal Comparison Method

Hamzah Eteruddin*[1], Abdullah Asuhaimi bin Mohd Zin[2], Belyamin Belyamin[3]
[1] Universitas Lancang Kuning, Jl. Yos Sudarso, km 8 Rumbai Pekanbaru 28265, Indonesia
[2] Universiti Teknologi Malaysia, Skudai Johor Bahru Johor 81310, Malaysia
[3] Politeknik Negeri Jakarta, Jl. Prof. Dr. G.A. Siwabessy, Kampus UI Depok, Depok 16425, Indonesia
*Corresponding author, e-mail: hamzah128@gmail.com

Abstract

This paper discusses the protection system which is the most important part in a power system. Increased protection system reliability determines to improve the performance of the entire electrical system. Differential scheme denoted a very reliable method to secure the protection zone. There have been some studies on this topic. However, still need further study in order to obtain a better system, simple and reliable. The resulting model is made in gradually. Each stage is verified to reduce operational errors. Validation was done using the composite method of current and voltage signals, and the sigma delta algorithm as the analog to digital converter. Numerous computing were done to simulate the differential protection system on the underground cable transmission line 420 kV along the 58.5 km, using Matlab / Simulink. The results showed that the proposed method is effective enough to minimize the percentage of errors.

Keywords: *Modeling and Simulations, Line Differential Protection, Sigma Delta Algorithm*

1. Introduction

Power system must operate in a safe manner at all time. However, even with perfect designs, faults might occur. The faults will lead to a partial system or total blackout. To protect the system against the disturbances that occurred, a protection system is essentially required. There are many kinds of protective relay available to solve this problem.

The main requirements in a power system protection include speed, selectivity, sensitivity, security, dependability, reliability. Selectivity requires that the protection system must be dependable in identifying faults in its zones of protection. Sensitivity is the ability of the relay to pick up even the smallest possible faults. Security is a property used to characterize a false tripping, or the capability of the protection system to refrain from operating when it should not operate. Dependability is the degree of certainty that the relay will operate correctly. Reliability requires that the protection system be operable, that the overall design will ensure appropriate protective action, even if some portion of the protective apparatus may have failed. This is achieved by using equipment of high quality, performing routine testing to ensure that the equipment remain operable, and designing a protective system that has redundancy [1]-[4].

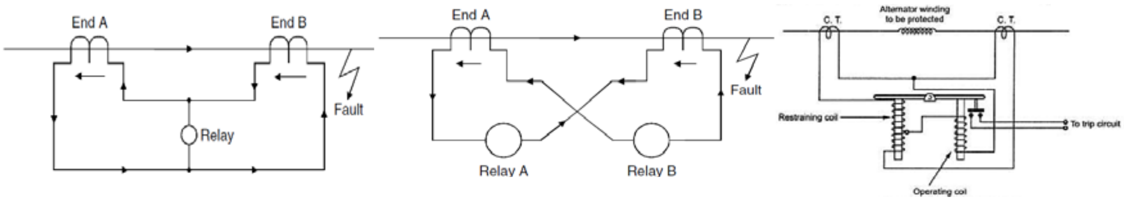
A transmission line is the most important and integral part of a power system. Due to the occurrence of more than 80% of disturbances or short-circuit faults in an overhead line, this section has become the most vulnerable part of the electrical system [5]-[8]. Therefore, it is necessary having designed a reliable protection system to protect against interferences..

The disadvantages of distance and directional over current relay on the transmission line include; (1) The relays cannot disconnect disorder instantly on both ends of the line if a fault occurs at the end of the line. (2). Coordination is achieved by adjusting the time delay of the relay mounted on a channel next to the concept of main and backup protection. As a result, termination disturbance will be slow in line with the delay time of the relay that works on each protection zone.

To solve this, protection of transmission line can be done by applying differential protection (for short transmission line) and pilot relay protection (for long distance transmission). The current differential protection is based on the Kirchhoff's first law, whereas the impedance type is based on Kirchhoff's second law [4], [9], [10]. When a fault occurs within the protected zone, the current flowing into the protected line is unequal to those flowing out from the

Received December 4, 2013; Revised January 17, 2014; Accepted Feb 6, 2014

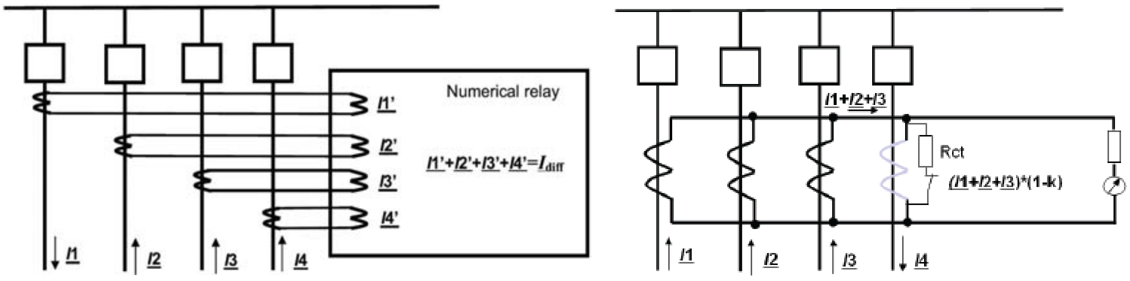
protected line. Therefore, it requires a reliable communication channel to compare the currents at the transmission line terminals. Current differential protection has been proven effective during evolving, inter-circuit and crossing country faults. Moreover, it is unaffected by power swings, mutual coupling and series impedance unbalances [10].



(a). Balanced Current System (b). Balanced Voltage System (c). Percentage Differential System

Figure 1. Different types of Differential Relay schemes

Differential protection, as its name implies, compares the currents entering and leaving the protected zone. It operates when the difference between these currents exceeds a pre-determined value. There are 3 types of differential relay protection: (1) current differential relay, (2) biased beam or percentage differential relay, and (3) voltage balanced differential relay [11], [12], as shown in Figure 1.



(a). Low Impedance Type (b). High Impedance Type

Figure 2. Differential Relay schemes based on Impedance

Meanwhile, impedance protection consists of two types of differential relays: high impedance and low impedance, as shown in Figure 2. High impedance is based on Merz-Price circulating current principle. Low impedance is parallel to all current transformers which function to measure the current sum [4], [13].

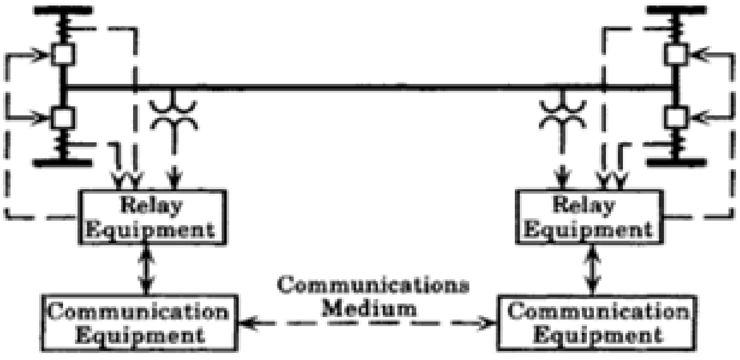


Figure 3. General view of line differential protection system

Line differential protection is a mechanism of protection in power system, equipped with a communication tool. Each relay protection installed can communicate interactively. The transmission media usually used in transmission line protection are: 1. Power Line Carrier (PLC), 2. Microwave, 3. Fiber Optics, 4. Communication Cable [1]. Line differential is commonly called as pilot protection or tele-protection. The protection challenges for distribution lines are identical to the transmission lines [14].

The relay systems at each end of the transmission line function to monitor the local currents and voltages. These signals, or also known as derived response, are sent to the local relay equipment only, where trip signals may be generated and sent to the circuit breakers at the local relay location. (Signal paths in Figure 3 are shown by dashed lines.) Additional equipment is provided to allow each relay to send signals to the relay equipment at the remote end of the line. This provides each relay with important new information regarding the need for tripping, namely the view of the disturbance seen from both ends of the line. Both relays can now operate on the basis of the condition, as observed from both relay locations. [1]

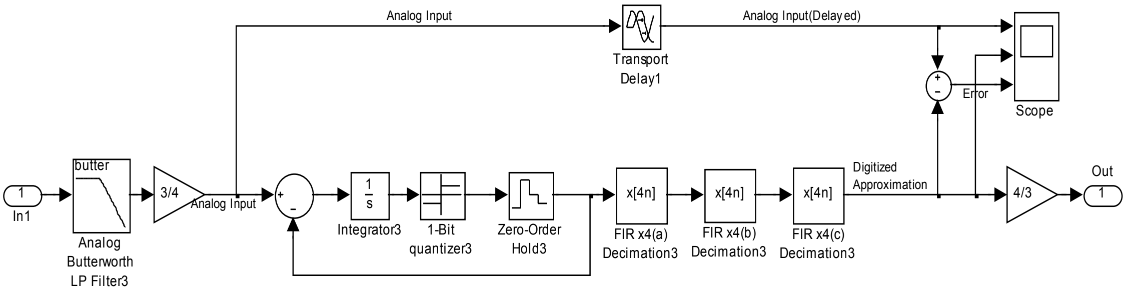


Figure 4. Sigma Delta ADC

Figure 5. Schematic representation of the Underground 420 kV Cable System

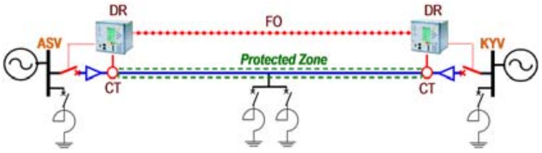


Figure 6. Schematic representation of the Differential Protection Scheme over Underground 420 kV Cable System

2. Research Method

Relay computer modeling is commonly applied to achieve a proper protection method for specific system. At the moment, it is difficult to obtain an accurate relay computer model, since the manufacturers offer products with a variety of algorithms and features that may significantly change the operation of relays under specific conditions and states.

A model proposed by M. Sztykiel, et al. (2010) was applied in this research. They constructed a model of protective relays to analyze a specific relay model and High Voltage AC cable system by using EMTDC/PSCAD software. An illustration on the simulation of differential protection on underground cable lines of 420 kV is shown in Figure 5 and Figure 6. The technical data are shown in Tables 1-2 [18].

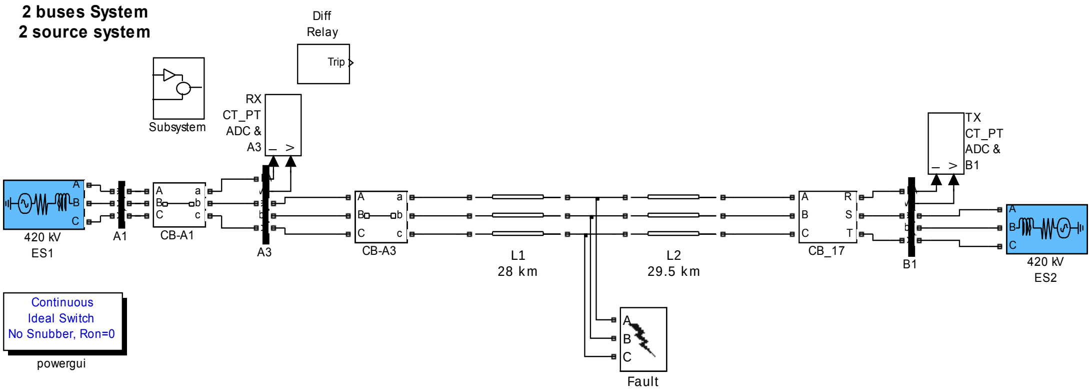


Figure 7. MatLab / Simulink representation of the Underground 420 kV Cable System

TABLE 1. TECHNICAL DATA OF XLPE UNDERGROUND 420 KV CABLE

Description	Value
Cross-section of conductor (mm^2)	1600
Diameter of conductor (mm)	52
Insulation thickness (mm)	27.0
Diameter over insulation (mm)	110.0
Cross-section of screen (mm^2)	185
Outer diameter of cable (mm)	127.0
Capacitance (μF/km)	0.21
Inductance (mH/km)	0.50
Charging current per phase (A/km)	14.9

TABLE 2. TECHNICAL DATA OF CABLE SUPPLY SOURCES

Supply Source	Voltage (kV)	Short-circuit impedance (Ω)
ES1	420	0.829 + j16.60
ES2	420	0.839 + j16.78

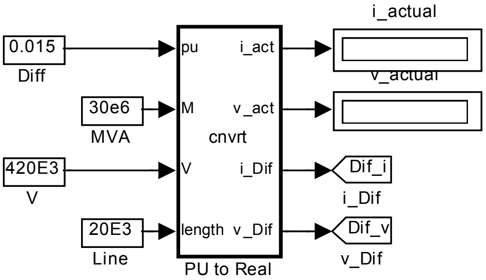


Figure 8. pu to Real Conversion Block

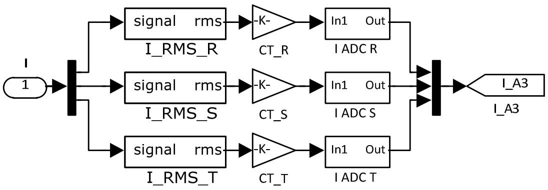


Figure 9. Three phase Analog-to-Digital Converters (ADC)

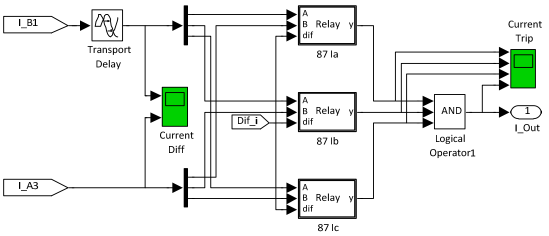


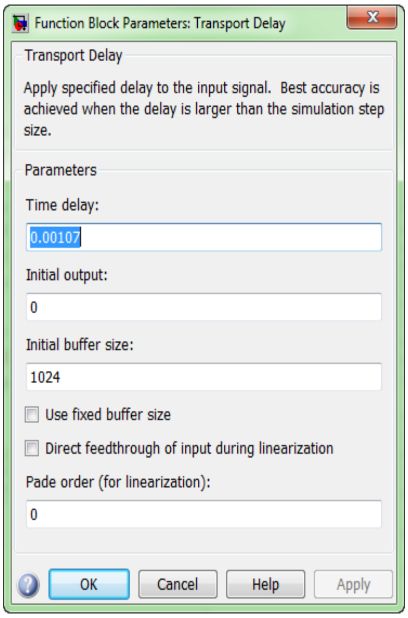
Figure 10. Three phase Differential Relay Block

These papers present the simulations of line differential protection in Matlab/Simulink environment, as shown in Figure 7. It simulates three phase, underground cable with two sources, 50Hz, 420 kV, with 58.5 km length was used in this system [18]. Detailed design of each block is illustrated separately in Figures 8 to 13.

The model was based on a per - unit (pu) system, therefore, voltage and power base were required. To determine the minimum current difference (Idiff) setting, we used per-unit to real conversion block as shown in Figure 8. The current was set slightly above the leakage current that occured in the underground cables used.

At the local (A3) and remote side (B1), CT and CVT were fitted on both sides to measure the current and voltage on each phase. Current and voltage analog signals per phase were converted into digital data by using the Analog-to-Digital Converter (ADC) block, as shown in Figure 9. The difference between the method in the study made by R. K. Aggarwal and A. T. Johns (1989), and the model discussed in this study is that R. K. Aggarwal and A. T. Johns (1989) combined the current and voltage signal in the sample & hold multiplexer, and converted them into digital data at the ADC. Meanwhile, the model discussed in this paper converts the current and voltage signals per phase directly into digital data by using the ADC and then passes them to the three phase differential blocks.

Further, the three phase differential relay block as shown in Figure 10, was set to one unit relay each phase. The function was to differentiate the magnitude of current and voltage on both sides (local and remote). The local side was connected directly to the relay whereas the remote side was connected to the transport delay block. The function of this block is to put channel time delay (propagation) factors for the remote signal. The channel time delay is set 1.07 milli-second [18], as shown in Figure 11.



Function Block Parameters: Transport Delay

Transport Delay

Apply specified delay to the input signal. Best accuracy is achieved when the delay is larger than the simulation step size.

Parameters

Time delay:
0.00107

Initial output:
0

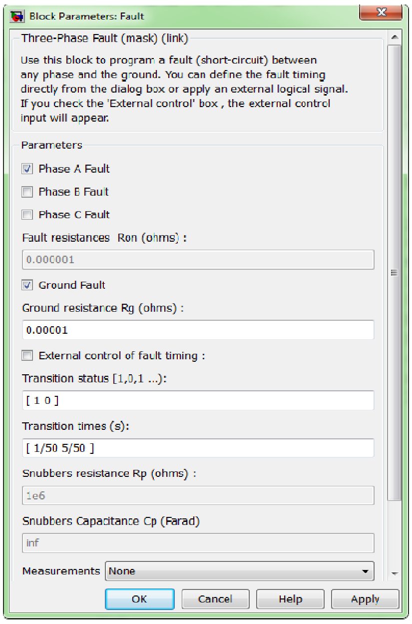
Initial buffer size:
1024

☐ Use fixed buffer size

☐ Direct feedthrough of input during linearization

Pade order (for linearization):
0

Figure 11. Channel time delay setting



Block Parameters: Fault

Three-Phase Fault (mask) (link)

Use this block to program a fault (short-circuit) between any phase and the ground. You can define the fault timing directly from the dialog box or apply an external logical signal. If you check the 'External control' box , the external control input will appear.

Parameters

☑ Phase A Fault

☐ Phase B Fault

☐ Phase C Fault

Fault resistances Ron (ohms) :
0.000001

☑ Ground Fault

Ground resistance Rg (ohms) :
0.00001

☐ External control of fault timing :

Transition status [1,0,1 ...):
[1 0]

Transition times (s):
[1/50 5/50]

Snubbers resistance Rp (ohms) :
1e6

Snubbers Capacitance Cp (Farad)
inf

Measurements None

Figure 12. Setting of Fault

A three phase differential relay block output is binary; 0 means the relay is off and 1 means on. During disturbances within the protected region, there will be differences between current and voltage at every phase on both channels (local and remote). Therefore, the relay was set to provide a trip signal when there was a discrepancy in current or voltage in every phase. Hence, the relay would set the signal output of each relay, which were connected to AND gate.

In this study, we arranged the Scenario Simulation model. The disturbance occured at the middle of line an underground cable for 80 ms. Fault begins at 20 ms (1/50 seconds) and ended at 100 ms (5/50 seconds), as shown in Figure 12. On this fault parameter block, the types of the simulation fault were set up. Matlab R2010a 32 bits, with ode23tb solver configuration parameters were used in this simulation. Other settings used continuous signal, ideal switch, and neglected snubbers and resistance in switching devices (Ron = 0).

The main decision block, as shown in Figure 13 was used to composite the current and voltage tripped signal. This block consisted of three sub-blocks, the Current, Voltage and subsystem. Current and Voltage block represented the output of current and voltage signal tripping signal, respectively. Subsystem was the block to composite where both signals tripped, as shown in Figure 14. The delay block functioned to minimize the measurement error that would occur. To solve the problem, we proposed ‘off delay’ and ‘on delay of 20 ms respectively. The results obtained were in line to the differential relay principle.

3. Results and Analysis

The result are presented according to different cases: Case 1: Single Line to Ground Fault (SLGF), Case 2: Line to Line Fault (LLF), Case 3: Double Line to Ground Fault (2LGF), Case 4: Three Line Fault (3LF), Case 5: Three Line to Ground Fault (3LGF).

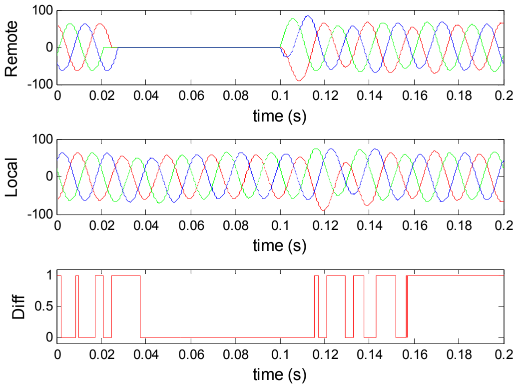


Figure 15. Single Line to Ground Fault currents waveform

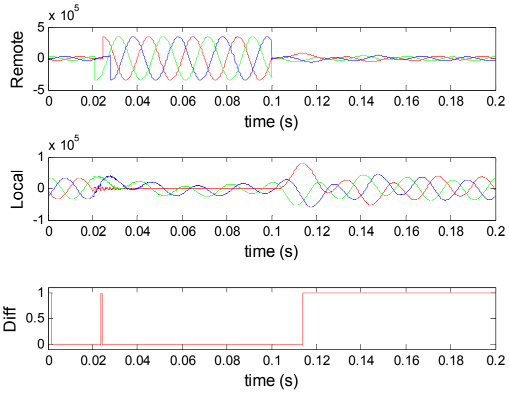


Figure 16. Single Line to Ground Fault voltage waveform

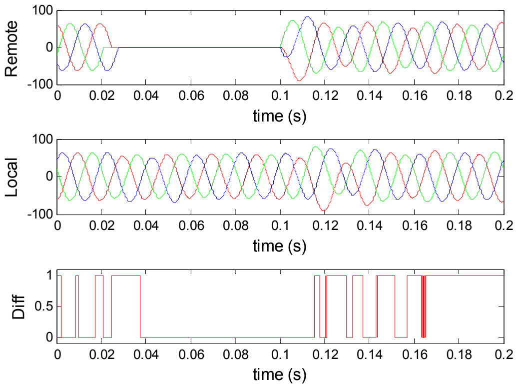


Figure 17. Double Line Fault currents waveform

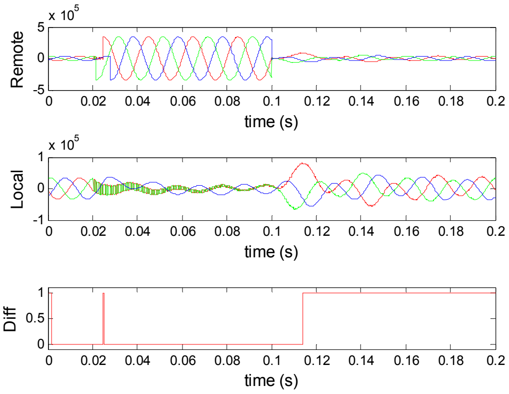


Figure 18. Double Line Fault voltage waveform

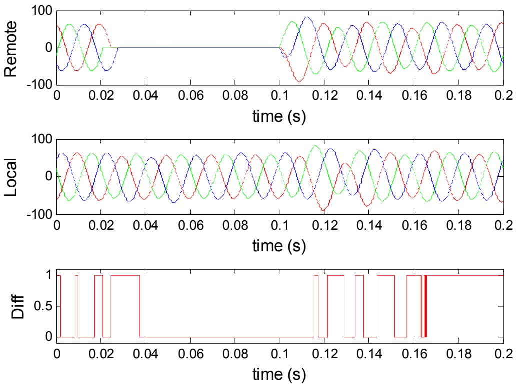


Figure 19. Double Line to Ground Fault currents waveform

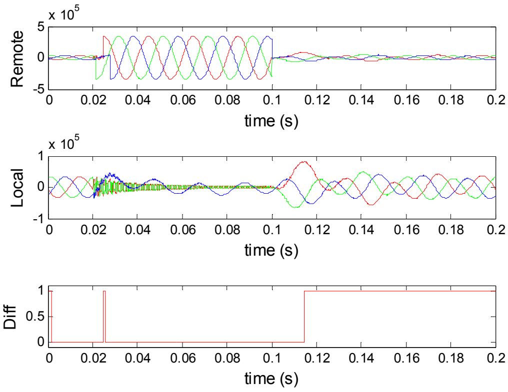


Figure 20. Double Line to Ground Fault voltage waveform

The main principle of the differential relay was to compare both ends of the protected area. Simulations for each case were done in similar manner, by comparing the current and voltage respectively at both ends. The results for all cases are illustrated in Figures 15 to 24.

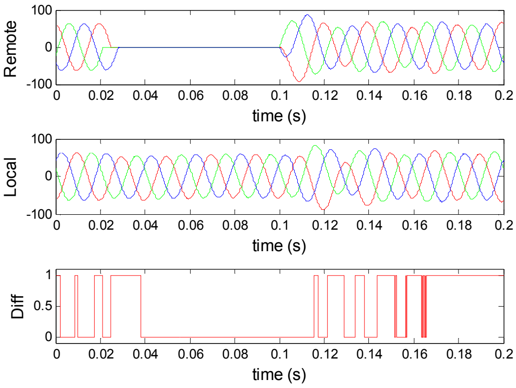


Figure 21. Three Line Fault currents waveform

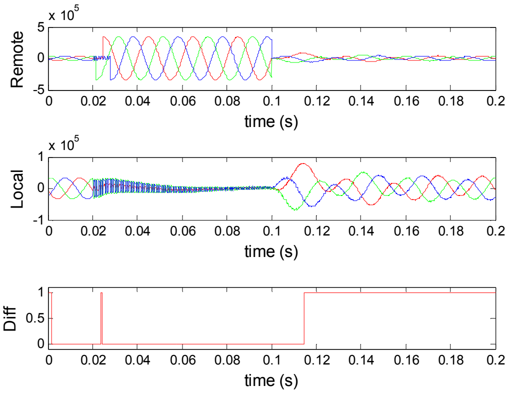


Figure 22. Three Line Fault voltage waveform

Figures 16, 18, 20, 22 and 24 show the respective magnitudes. There are three charts in each figure: Remote, Local and Diff. Remote and Local list the results of measurement from the local and remote side respectively, with red, green and blue color-code for phase A, B and C respectively. Diff denotes the difference between the two sides which were measured in binary (0;1) i.e. signal trip. It represents the difference of current or voltage magnitude at both ends.

The current differential signal trips are illustrated in Figures 15, 17, 19, 21 and 23, whereas the voltage differentials signal trips are shown in Figures 16, 18, 20, 22 and 24. Figures 15, 17, 19, 21 and 23 show that when the fault occurred (at t = 20 ms), the magnitude of current decreased significantly (almost to zero) at the remote side compared with the local side. Voltage on the remote side increased almost five times the normal one in all phases. At the local side, the phase voltage was zero at the faulted line, and the other phase reduced to half of the normal voltage.

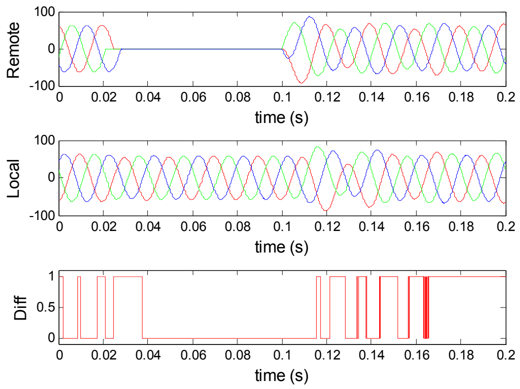


Figure 23. Three Line to Ground Fault currents waveform

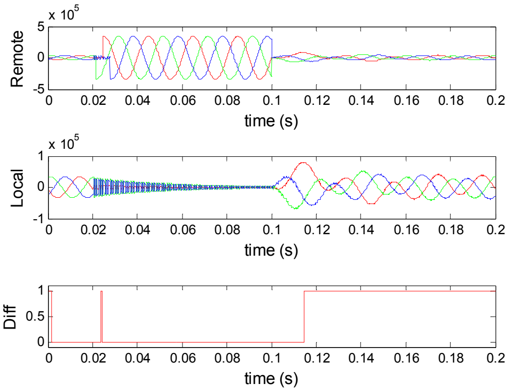


Figure 24. Three Line to Ground Fault voltage waveform

There were errors in the current or voltage signal trips, as shown on Figures 15 to 24. During fault, the signal trip must display the value "0", however, Figures 15 to 24 shows the signal trip of "1". It was a vital error to be overcome. In the opposite, on pre-fault and post-fault, the signal trip must indicate "1", however, the figures show the value of "0". This error or unwanted tripping was due to the CT saturation or data mismatches caused by delays that occurred, when the signal was transmitted from the remote area [19]. The delay was affected by the distance between both ends of the protected zone, which resulted in phase shifting of the transmitted signal. This caused errors in the results of current or voltage signal trip.

To solve this error, many researchers have implemented synchronized sampling GPS time information at all terminals of the protected line [20-23]. This paper proposes a merger of current and voltage signal trip to get more accurate results or to fix these errors. We used Main Decision Block (MDB), as shown in Figure 13 is the method used. The detailed MDB subsystem is shown in Figure 14. The output of this block was main signal trips that were used to connect or disconnect the circuit breaker, namely the main signal trip.

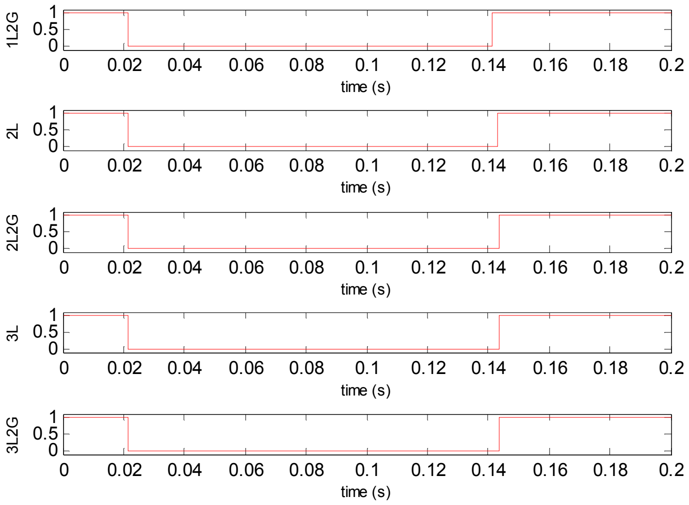


Figure 25. Main Signal trip logic

The Main Signal Trips for each case are shown in Figure 25. The figure shows the main signal trip command the breaker to trip a moment after the fault occurred. When fault had been recovered, the signal trips were also to closed the breaker a moment after fault recovery. In general, the pattern of tripping signal was in compliance with the principle of differential relay. The data of signal trip in Figure 25 is tabulated in Table 3. The Figure shows that for all cases, the relay commanded the breaker to trip at an equal period of time i.e. 1.4648 ms after the start of the fault at 20 ms. The fastest recovery time of 41.4561 ms was obtained from single phase to ground fault (SLGF) whereas the longest one with 43.5303 ms was detected from the double phase to ground fault (2LGF) after the end of fault at 100 ms.

Table 1. Result of Relay Response

Case Type	Time Breaker Off (m sec)	Time Breaker On (m sec)
Case 1: (SLGF)	21.4648	141.4561
Case 2: (LLF)	21.4648	143.0421
Case 3: (2LGF)	21.4648	143.5303
Case 4: (3LF)	21.4648	143.4083
Case 5: (3LGF).	21.4648	143.4082

4. Conclusion

A new integrated differential protection method for line differential protection of transmission lines is described in the paper. The Main Decision Block (MDB) is one method to fix errors (to achieve accurate results) in the current and voltage signals trip.

Successful simulation in this study had proven the advantages of the proposed technique. However, a future study is still needed to simulate communication and signal processing technologies to achieve a bright future for the practical applications of the proposed relay and its associated method.

References

[1] P. M. Anderson. *Power System Protection*: Wiley. 1999.

[2] ALSTOM and A. Staff. *Network Protection and Automation Guide: Protective Relays, Measurement and Control*: Unknown Publisher. 2011.

[3] A. F. Sleva, Protective Relay Principles: Taylor & Francis, 2010.

[4] J. Holbach. *Comparison between high impedance and low impedance bus differential protection.* Power Systems Conference. 2009: 1-16.

[5] M. Singh, K. B. Panigrahi, and R. P. Maheshwari. *Transmission line fault detection and classification," in Emerging Trends in Electrical and Computer Technology (ICETECT).* 2011 International Conference on. 2011: 15-22.

[6] M. Geethanjali and K. S. Priya. *Combined wavelet transfoms and neural network (WNN) based fault detection and classification in transmission lines.* Control, Automation, Communication and Energy Conservation, 2009. INCACEC 2009. 2009 International Conference on. 2009: 1-7.

[7] R. Dhua and C. Koley. *Simulation of Frequency Dependent Transmission Line for Identification of Faults and Switching over Voltages.* Proceedings of the International Conference on Frontiers of Intelligent Computing: Theory and Applications (FICTA). vol. 199, S. C. Satapathy, S. K. Udgata, and B. N. Biswal, Eds., ed: Springer Berlin Heidelberg. 2013: 311-320.

[8] N. Tleis. *Power Systems Modelling and Fault Analysis: Theory and Practice*: Elsevier Science. 2007.

[9] K. Tsuji. Protection relaying scheme based on fault reactance operation type. *Electrical Engineering in Japan*. 2009; 168: 29-40.

[10] Z. Min, D. Xinzhou, Z. Q. Bo, B. R. J. Caunce, and A. Klimek. *A New Current Differential Protection Scheme for Two-Terminal Transmission Lines*. Power Engineering Society General Meeting, 2007. IEEE. 2007: 1-6.

[11] L. Hewitson, M. Brown, and R. Balakrishnan. *Practical Power System Protection*: Elsevier Science. 2004.

[12] U. A. Bakshi and V. Bakshi. *Protection And Switchgear*: Technical Publications. 2009.

[13] T. E. T. Association and I. o. E. Engineers. *Power System Protection 3: Application*: Institution of Electrical Engineers. 1995.

[14] R. Hunt, S. McCreery, M. Adamiak, and A. King. *Application of Digital Radio for Distribution Pilot Protection and Other Applications*. Protective Relay Engineers, 2008 61st Annual Conference for. 2008: 310-333.

[15] R. K. Aggarwal and A. T. Johns. A differential line protection scheme for power systems based on composite voltage and current measurements. *Power Delivery, IEEE Transactions on*. 1989; 4: 1595-1601.

[16] R. K. Aggarwal and A. T. Johns. *New approach to Teed feeder protection using composite current and voltage signal comparison*. Developments in Power Protection, 1989, Fourth International Conference on. 1989: 125-129.

[17] Matlab. *The Language of Technical Computing.* 7.10.0 (R2010a) ed: The Math Works Inc., 2010.

[18] M. Sztykiel, C. L. Bak, W. Wiechowski, and S. Dollerup. *Line differential protection scheme modelling for underground 420 kV cable systems: EMTDC/PSCAD relays modeling.* Modern Electric Power Systems (MEPS), 2010 Proceedings of the International Symposium. 2010: 1-6.

[19] F. Namdari, S. Jamali, and P. A. Crossley. Power differential based wide area protection. *Electric Power Systems Research*. 2007; 77: 1541-1551.

[20] G. Houlei, S. Jiang, and H. Jiali. *Development of GPS synchronized digital current differential protection*. Power System Technology, 1998. Proceedings. POWERCON '98. 1998 International Conference on, 1998; 2: 1177-1182.

[21] H. Gao, J. He, and S. Jiang. GPS synchronized digital current differential protection for transmission lines. *Electric Power Systems Research*. 2002; 62: 29-36.

[22] I. Hall, P. G. Beaumont, G. P. Baber, I. Shuto, M. Saga, K. Okuno, et al. *New line current differential relay using GPS synchronization*. Power Tech Conference Proceedings, 2003 IEEE Bologna. 2003; 3: 8.

[23] S. Dambhare, S. Soman, and M. Chandorkar. *A GPS Synchronized Current Differential Protection of Transmission Lines*. Proc. of 16th Power Systems Computation Conf.(PSCC'08), Glasgow, Scotland. 2008.